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Report of the External Review Committee for the Department of Applied Mathematics, Naval Postgraduate School

22 June 2010

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Executive Summary

- The mathematical sciences will play an ever-increasing and vital role in the success of the US military in the 21st century. The Department of Applied Mathematics at NPS contributes in three profound ways by: 1) providing service to more than 30 curricula, 2) providing exceptionally well trained instructors to the USMA at West Point, and 3) having faculty who conduct use-inspired basic research that is relevant to the needs of the military.
- The NPS plays a unique role in the national landscape of higher education since at NPS students with relevant military experience are brought together at the graduate level in significant numbers to study issues important to the Navy and other services. The ability to easily handle classified research and classified thesis work is another aspect of NPS that is truly unique.
- The academic curriculum is very well designed and the department runs a highly successful MS program and a small but successful doctoral program. Students are well served by the program and very pleased with the quality of their education. The faculty conduct high quality research and would be competitive at top ranked civilian institutions.
- The department faces two major challenges. The first is faculty renewal and the second is the limited number of graduate course offerings.
- The first challenge can be met by establishing a regular sabbatical program so that NPS faculty can spend time at other institutions, by bringing sabbatarians from other institutions to the NPS for their sabbaticals, and by creating a program of teaching post-docs/visiting Assistant Professors who would teach a limited number of courses and conduct research with faculty members.
- In the short term, the second challenge can be met by funding a small number of additional graduate courses (bringing the total number of graduate offerings to 8-10 per year) on a regular and sustained basis (of the order of 5 years) so that other departments in NPS can count on those courses for enhancing the education of their students. If this experiment is successful, the courses should be funded on a permanent basis and expansion of the Departmental Ph.D program can be considered, perhaps after the next external review.
- In the long term, the second challenge can be met by revision of the current threshold model for funding in which courses of fewer than seven students receive no funding and by collaborative work with the Superintendent of the USNA to reinstate the Applied Mathematics curriculum at NPS as a pipeline of instructors to the USNA.

Introduction

We conducted our review 7-8 June 2010. However, we interacted extensively with Chair Borges and others in the weeks leading up to the formal review. Prior to the review period we had the opportunity to analyze the extensive self-study prepared by Chair Borges, which we encourage all subsequent reviewers to read. The self-study is very thorough and extremely well-written, and was an immense help to us in preparing for our visit. During the review period, we met with the senior leadership at NPS, the Applied Mathematics Department chair, other academic leaders in the department, faculty, and students, including some working on degrees outside of the department.

It is absolutely clear that the mathematical sciences will play an ever-increasing and vital role in the success of the US military in the 21st century. The Department of Applied Mathematics at NPS contributes in three profound ways. First, it provides important service to more than 30 academic curricula at NPS in the form of course offerings. These courses offer students in academic programs outside of applied mathematics a vital perspective on their own disciplines. Such courses also allow students to see how apparently disparate fields can be understood in the common framework that precise mathematical thinking provides. Comments from students were very specific about the exceptional value added to their experiences through courses in applied mathematics; these are described below.

The Department of Applied Mathematics also provides exceptionally well prepared instructors to the Department of Mathematical Sciences at the United States Military Academy at West Point. NPS graduates who join the USMA faculty play a vital role in educating leaders of character for the US Army and the nation. As the Department of Mathematics at the US Naval Academy ramps up its military faculty strength in the future, it would be exceptionally well served by sending officers to earn degrees in applied mathematics at NPS prior to a USNA faculty posting. This is an excellent structure in which officers with field experience are instructors at the undergraduate military academy, where they can serve as role models.

Finally, faculty in the Department of Applied Mathematics conduct important, cutting-edge research that is motivated by the needs of the Department of the Navy and Department of Defense. The self-study contains strong evidence of an exceptionally vibrant and active faculty, and having this kind of world-class talent devoted to serving the needs of the Navy is an important national asset. These faculty work in what Donald Stokes has called Pasteur's quadrant of use-inspired basic research (Stokes 1997), and this is exactly the correct intellectual focus for NPS faculty.

Furthermore the NPS plays a unique role in the national landscape of higher education. Nowhere else in the nation are mature students with relevant military experience brought together at the graduate level in significant numbers to study issues important to the Navy and other services. NPS in general, and the faculty in the Department of Applied Mathematics in particular, are exceptionally willing and able to handle the specific needs of graduate students whose undergraduate preparation is either somewhat short of expectations or somewhat more dated than is typically the case. The ability to easily handle classified research and classified thesis work is another aspect of NPS that is truly unique. Indeed, that the Department of Applied Mathematics offers a master's degree with a thesis at all is increasingly unusual: most (if not all) other top-tier graduate programs in pure or applied mathematics put the vast majority of their emphasis on the Ph.D. program, and Master's degrees are seen in part as consolation prizes for Ph.D. students who fail to earn their Ph.D. Given the needs of the Navy and the Department of Defense, this emphasis on the professional Master's programs is entirely appropriate. We also

note that the model of civilian instructors for graduate students is a good one, since at the graduate level students must be able to challenge their instructors as they wrestle with research problems and it is more likely that junior officers will do so if their instructors are civilians, but ones who understand the needs and culture of the military.

Another distinctive feature of the Department of Applied Mathematics at NPS is the caring faculty who are totally dedicated to student success. Students we interviewed consistently praised the department for its strong culture focused on teaching and helping students learn. Data from the self-study show the department's exceptionally strong student opinion (SOF) scores (as compared to NPS averages) and illustrate a long tradition of great teaching.

The main shortcoming that we identified with the applied mathematics program is that the department is not able to consistently offer an appropriate variety of graduate level mathematics courses. The vast majority of their teaching effort is devoted to 1000 and 2000-level courses to allow students who have been away from academia for a considerable period to recover their technical skills. Faculty focused on doing this kind of teaching *and doing it well* are typically unable to achieve their full potential in scholarship. We believe that increasing graduate offerings in a department that is demonstrably outstanding would be a very wise use of scarce institutional resources. Additional specific ideas concerning this issue will be addressed in our recommendations.

Academic Programs / Curricula

The Department of Applied Mathematics at NPS has 15 full-time tenure track professors (and one who is on long-term, already 5 years, leave of absence) representing three main areas of applied mathematics: 1) Applied Analysis, 2) Numerical Analysis/Scientific Computing and 3) Discrete Mathematics. In response to a recommendation made in the department's 1985 self-study, which was the last self-study conducted prior to this one, the department made an effort to reconstitute itself into these three groups. This configuration gives the department sufficient breadth to address a wide spectrum of military and other applications of applied mathematics and the number of faculty in each subgroup is large enough to promote research collaboration among the faculty. The publication list of the department shows that collaborations occur rather frequently. This configuration also allows students in science and engineering to see how applied mathematics unites the various fields of study. That is, mathematics taught by applied mathematicians is perhaps the most critical factor in getting students to understand the interconnectedness of the various branches of science and engineering (much as physics taught by physicists ties together many branches of engineering).

The department has the research talent and size to run a successful Ph.D. program. At the moment the department produces an average of about one Ph.D. student per year. The department also supports a Master's degree program, with a Master's thesis required of students for the successful completion of their degree. The student participants in the program are mostly young officers from the Army who have been away from formal schooling in mathematics for over five years. The department's Master's program has been singularly successful in helping these students reach their educational goals despite their long absence from the classroom. This is accomplished by intensively reviewing undergraduate coursework in the first and second quarters of their stay at NPS and then moving them into master's level courses. The success of this program is a direct result of the department's attention to excellent teaching and the maturity and strong work ethic of its students. The members of the faculty are also very generous with their time. In particular they frequently offer reading courses to replace classes that do not run as a

result of under-enrollment and the funding model used at NPS (see below). The trajectory that leads students in the program from remedial undergraduate courses to a Master's thesis in twenty-four months is quite remarkable and virtually unique in North America.

The department is running a successful doctoral program. The program is unique in that it allows for the possibility that students may produce a Ph.D. thesis consisting of classified results. Students who complete the Ph.D. have many opportunities available to them, including teaching at the service academies and participation in government research laboratories and think tanks. On the other hand, the program places a severe strain on the resources of the department. The upper level courses needed to sustain a Ph.D. program are chronically underpopulated, which forces the department either to run courses below capacity or to offer reading courses. Neither activity is recognized by the budgetary policy used at NPS, which reimburses departments only for courses with seven or more students (a threshold funding model). The department follows the standard procedure of administering both written and oral exams to doctoral candidates. The thesis defense committee typically consists of some members of the department along with an outside participant who may be from NPS or from another academic institution. The Ph.D. program is very expensive in terms of the time and energy expended by the faculty.

Student Opinion Forms are used to measure the quality of the teaching, which is carried out in the classroom. Faculty are occasionally visited by their peers, and a report is submitted to the chair of the department. During our visit we interviewed three candidates for the Master's degree and one student who recently completed his doctoral studies in Applied Mathematics, all of whom were Army officers. The students were uniformly pleased with the educational experience they had received at NPS. They were delighted with the degree of attention they had received from the faculty and they were satisfied with the curriculum that was made available to them. The Ph.D. student we interviewed reported his experience at NPS as "marvelous". The MS students told us "[it was] a huge benefit to take pdes (partial differential equations) from Applied Math rather than a physics overview", "A great experience in a great department", "I'm able to do here what I could do nowhere else—a double MS", "The biggest advantage is the flexibility". The final comment refers to the structure of the MS program in Applied Mathematics in which a fixed set of core courses ensures technical skills but a sufficient number of electives allows the development of true expertise in the area of application.

According to the students the resources available to them were adequate. For example, they were given sufficient space in the department to support their work at NPS. Moreover since they were relieved of teaching assistant or grading responsibilities, they were able to concentrate fully on their studies and accelerate the rate at which they were able to make progress. All of them were pleased with the opportunities their advanced degrees afforded them. The Ph.D. student, for example, will report for three years to the Center for Army Analysis in Fort Belvoir and then will serve as an Assistant Professor at USMA for the following three years. All of the Master's degree candidates will eventually report to the Mathematics Department at USMA as instructors.

The range of opportunities available to graduate students in the Applied Mathematics program has increased as a result of innovations made by the Applied Mathematics faculty. It is now possible for students to obtain dual Master's Degrees in Applied Mathematics and another technical field. It is also possible for students to obtain certificates in other areas of studies, such as scientific computing or the mathematics of secure communication. The certificate programs acts as a mechanism for students to obtain a minor in a subject related to Applied Mathematics. The programs have had a positive impact by adding to the options available to students at NPS and by helping to fill seats in the 3000 and 4000 level classes offered by the department.

Faculty and Scholarship

We begin by noting that comparing the faculty at NPS with similarly sized nationally ranked public and private research universities is of limited value because of the uniqueness of the NPS as described above. Nevertheless, the scholarship of the faculty in the Department of Applied Mathematics compares well in this broader context. The specific details are given in the self-study so that here we simply note that the faculty publish in high quality outlets and generally at rates that are comparable to those of colleagues at Tier I research universities. Their research accomplishments are recognized by fellowship in a variety of professional societies and national academies of science. Once a sabbatical system (see below) is in place, a number of the faculty have CVs that will make them competitive for prestigious fellowships such as those of the John Simon Guggenheim Memorial Foundation.

The intellectual landscape of the department has vastly improved since the last review and is designed so that newly hired junior faculty will succeed, including a strong mentoring program. The number of research themes (three) and the topics (applied analysis, scientific computation, and discrete mathematics) are appropriate for a department this size and for the mission of the NPS respectively. The research themes provide intellectual cohesion and collaboration within the department and we saw no evidence of rivalry between the groups. Furthermore, a variety of emerging topics is likely to lead to stronger linkages between the groups. For example, questions of cyber security or environmental science (focusing on the environmental impact of military activity) could be addressed in any of the research themes.

The department has a regular seminar series, which brings in visitors from outside NPS. When appropriate, the seminars are held in conjunction with other departments (e.g. Operations Research).

We were surprised that regular sabbaticals appear not to be in the culture of NPS, and thus few of the members of the Department of Applied Mathematics have had a sabbatical. Sabbaticals are essential for faculty renewal, growth, and movement in new directions and need not be a year long, or even half-year. For example, the University of California, the premier public research university in the world, has a sabbatical policy in which faculty earn one quarter of sabbatical at full pay for 9 quarters of service (and scaled versions of that, such as one quarter at 2/3 pay for 6 quarters of service).

The departmental plan to use at least one of future retirements as a means of funding visiting faculty (sabbatarians from other institutions, teaching post-docs/research Assistant professors) is an excellent way to provide faculty renewal and intellectual growth without increasing the size of the permanent staff. It is not clear, however, when those retirements will occur.

Another means of faculty renewal is through teaching advanced graduate courses. However, since the termination of Curriculum 380 (Applied Mathematics) as a pipeline of instructors to the USNA, the number of regularly scheduled graduate courses in the Department of Applied Mathematics has been greatly constricted. Faculty have met the needs of students, mainly from the Army, by offering reading courses as overloads. Although the students were very enthusiastic about these courses, teaching such an overload, which is typically done by reading books or papers, is not as enriching and renewing for the faculty member as is formal instruction in which one has to organize and explain advanced concepts to students. Furthermore, since the reading courses are done on an ad-hoc basis, there is little opportunity for students in other programs to schedule them into their academic programs.

Resources and Organizational Support

The department is not resourced to offer an appropriate number of graduate level mathematics courses on a consistent basis. The department's inability to offer these courses prevents students from virtually every technical program on campus from being able to count on specific mathematics courses being offered at a suitable time. This in turn further limits enrollment, creating a negative feedback loop. This is unfortunate, since the evidence we gathered strongly indicates that graduate level mathematics courses are very good for students and are also of great benefit to the institution as a whole. We understand that recent changes in institutional procedures have significantly improved, but not completely solved, other long standing budget issues.

The office staff appears to be sufficient for the department, both in terms of size and capability, although the failure of budgeting the full cost of staff creates annual difficulties. Space must be a recurring issue for the institution as a whole, but at the current time it appears that the Department of Applied Mathematics has sufficient space. However, if our recommendation of increasing the number of post-doctoral researchers and adding sabbatarians and visiting assistant professors is followed, there is likely to be a shortage of space. Similarly, at the current time the department's equipment needs seem to be satisfied but this may change rapidly as post-docs and visitors join the department. Thus, the support the Department of Applied Mathematics receives from NPS seems sufficient overall at the current time.

The department is governed extraordinarily well; both the current chair and the previous chair have done an outstanding job leading and managing the department and its activities. The department has a strong program of mentoring for junior faculty, who are given every opportunity for success.

Strategy

The self-study describes a program that still suffers from a decision made by a former NPS President in 2001 to eliminate the Master's Degree program in Applied Mathematics (Curriculum 380). The program was partially reinstated in 2007 with the result that the department now confers a handful of Master's Degrees to Army officers (and is also accessible to officers from the Marines, Coast Guard [one of whom is joining the program in 2010-11], and NOAA Field Corp). Ironically, the Master's Degree program at NPS is currently unavailable to Naval officers. . This is in stark contrast to the Army where officers in the ORSA (49) career field are encouraged to pursue degrees in operations research, applied mathematics, or statistics. The resulting diversity of academic preparation strengthens the Army's analytical capability.

The future health of the advanced degree program at NPS depends greatly on the reversal of this policy. For example, without the full participation of the Navy in its own advanced degree program at NPS the number of students available to keep the 3000 and 4000 level courses running is likely to remain inadequate, forcing the department to continue the time wasting practice of offering numerous reading courses at the 3000 or 4000 level as a substitute for classes that do not run. This practice is expensive in terms of workload and sub-optimal in terms of the quality of instruction imparted to the student. This situation also has an impact on the Ph.D. program as candidates for this degree will also face the same prospect of taking required courses as reading courses as opposed to classroom courses. The Army's satisfaction with the program should be used as evidence of the usefulness of the program for the Navy as well.

The Department of Applied Mathematics offers a unique opportunity to junior officers who have been away from formal mathematical training for a significant period of time to regain their mathematical skills and to engage in a rigorous Master's Degree program. This curriculum reflects the needs of military officers who wish to return from the field to supplement their academic training. The program is well conceived and is exceptionally successful since almost all who enter the program emerge from it with a Master's Degree in Applied Mathematics. We give extraordinary credit to the faculty at NPS who have devised and successfully carried out this program for many years. We are not aware of any other high-quality Master's Degree programs that have been able to remediate students and lift them to such a high level of achievement consistently in such a relatively short amount of time. On the other hand, the program suffers from the constraint of getting its Ph.D. candidates through the program in a relatively short amount of time (usually three years). Even for the strongest of candidates this may not a long enough period of time to produce what they are capable of achieving. In civilian institutions, for example, it is not unusual for a student to take six years (four years post-MS) to produce a high-quality Ph.D. thesis. This is a problem, which extends beyond the Department of Applied Mathematics and even NPS itself, as many officers in civilian institutions are limited to three years to complete their advanced degree.

Conclusions and Recommendations

In conclusion, the Department of Applied Mathematics is a strong unit with intellectual vigor, breadth and depth; it had a collegial atmosphere in which faculty are given every opportunity to succeed. The department has leadership that is absolutely outstanding and strong mentoring of junior faculty.

The greatest challenge that the department faces is the intellectual renewal of the faculty, which can be accomplished through a formal sabbatical program, and the development of a sustained set of advanced graduate course offerings. These challenges can be overcome by actions at the departmental, decanal, and provostorial/presidential levels.

Action Items for the Department

The department should

- Continue to ensure quality within the Ph.D. program through the policy of requiring that at least one member of the thesis committee be from outside the department and, in the case of non-classified thesis, consider members from outside the institution.
- Use its limited resources to support postdoctoral colleagues, rather than trying to expand the Ph.D. program. This will help expose the faculty to new ideas from other departments across the country. This could include a program of teaching post-docs/research assistant professors. Two very natural themes, which links across the various groups and is of great relevance currently are cyber security and the impact of the military on the environment is another.
- Commit to offering 3-4 additional graduate courses (so that the total number of graduate offerings would be 8-10 per year) on a regular and sustained basis so that other departments at NPS can count on those courses for enhancing the education of their students.
- Begin course planning with sabbaticals in mind and develop a program to bring sabbatarians to the Department.

- Work with the NPS administration to reverse the Navy's policy that prohibits officers from taking the Master's Degree program in Applied Mathematics.

Action Items for the Dean

- Determine how the CDTEMS program, which is currently designed to support a civilian PhD student, could be reorganized to support teaching post-docs/visiting assistant professors or sabbatarians.
- Commit to funding the additional graduate courses described above in an experimental context. That is, fund these courses for a limited period of time (e.g. 5 years) after which enrollments in the courses can be assessed. If the courses are not reaching enrollment targets, then they should be scaled back. If they are then funding should be sustained. The experiment is key for: 1) the eventual growth of the Ph.D. program in Applied Mathematics and 2) the support that the Department of Applied Mathematics can provide to other departments through sustained graduate offerings.
- Consolidate courses offered by various departments with significant overlap in content. For example, the catalogue lists a number of courses offered by the Mechanical Engineering, Oceanography, Physics and Systems Engineering departments, all of which are essentially numerical analysis courses. Consolidating mathematics-oriented courses offered by various departments with significant overlap in their content would streamline the entire NPS program and would increase the number of students enrolling in some of the Applied Mathematics Department's upper level courses.
- Support the sabbatical program.

Action Items for Provost and President

- Reconsider the threshold model of funding courses so that courses taught to 4-6 students receive some funding. That is, courses with fewer than 4 students can effectively be run as reading courses and faculty overload but those with 4-6 require a different kind of educational model.
- Establish a NPS-wide sabbatical policy that will ensure faculty renewal.
- Work collaboratively with the Superintendent of the USNA to reinstate Curriculum 380 (Applied Mathematics) as a pipeline of instructors to the USNA.

Literature Cited

Stokes, D. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Brookings Institution Press, Philadelphia, PA